Monitoring soil management dynamics in European arable systems with Sentinel-1 and Sentinel-2

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Soil, the foundation of all terrestrial life, is under pressure

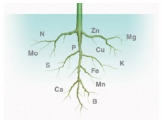
Agricultural practices promoting soil health focus on soil cover

Soil functions

- Biodiversity

- Water holding capacity

- Nutrient availability

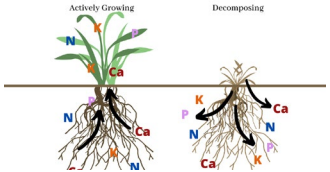


- Crop growth and yields

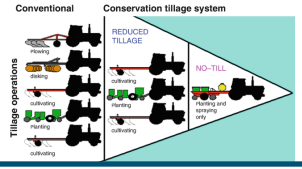
Practices promoting soil cover

- Crop diversification

- Cover crop



- Reduced tillage



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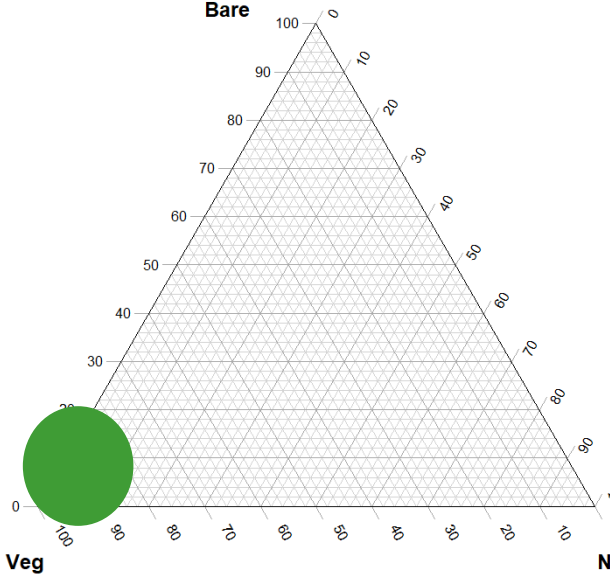
Quantifying field-level soil cover over time

Using 3 classes: bare soil, non-photosynthetic vegetation (NPV), and green vegetation



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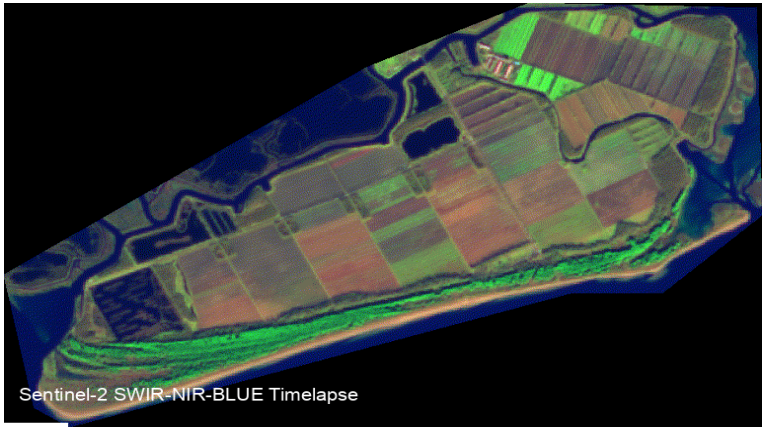
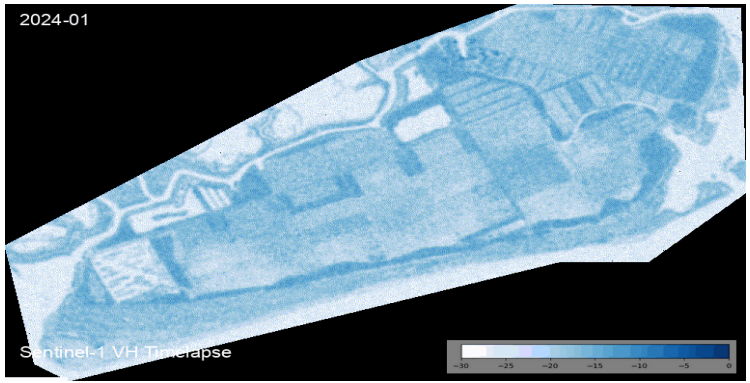
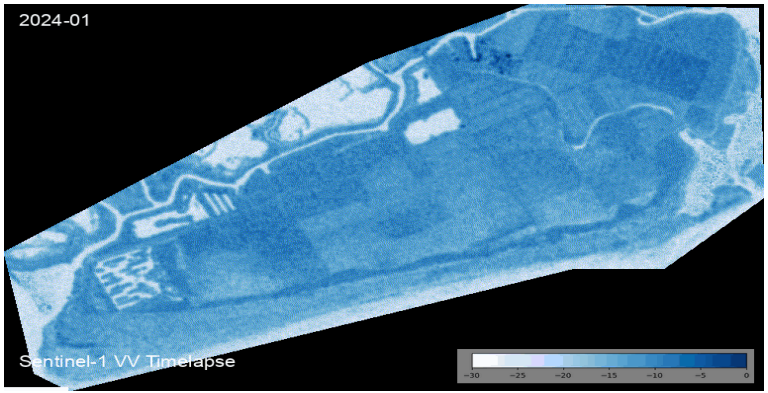
Monitoring soil cover dynamics using Sentinel data

Sentinel-2 and Sentinel-1 monthly composites in 2024 for a farm in Italy







Temporal resolution: ~5 days

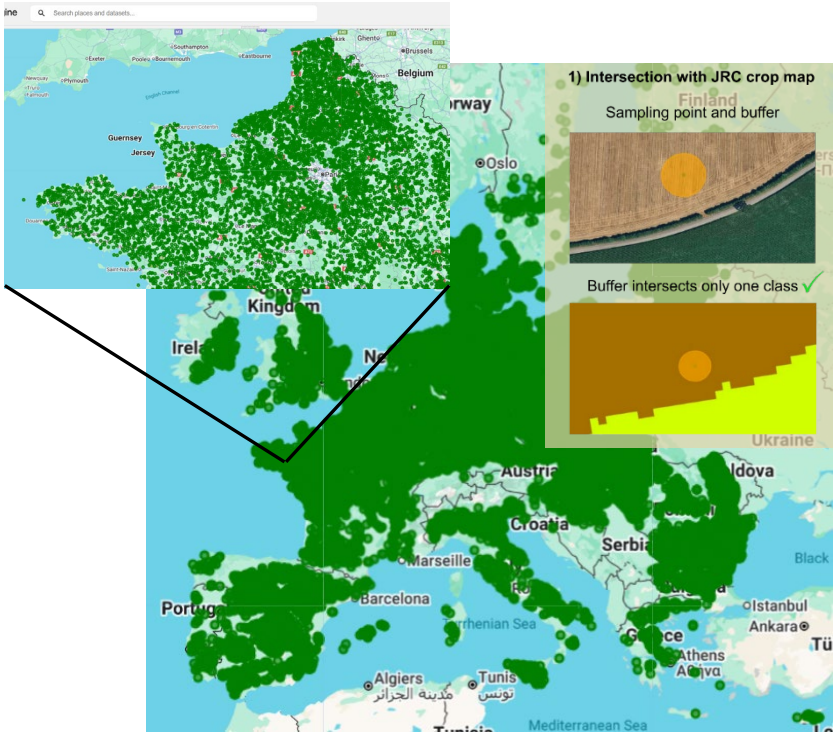
Spatial resolution: 10/20m

13 bands for Sentinel-2

2 polarization for Sentinel-1

Using LUCAS 2018 & 2022 ground photos as reference

6 photos are acquired for each agricultural field sampled across Europe (~60’000 after filtering)



5 geo-tagged and time-stamped ground photos are used per location

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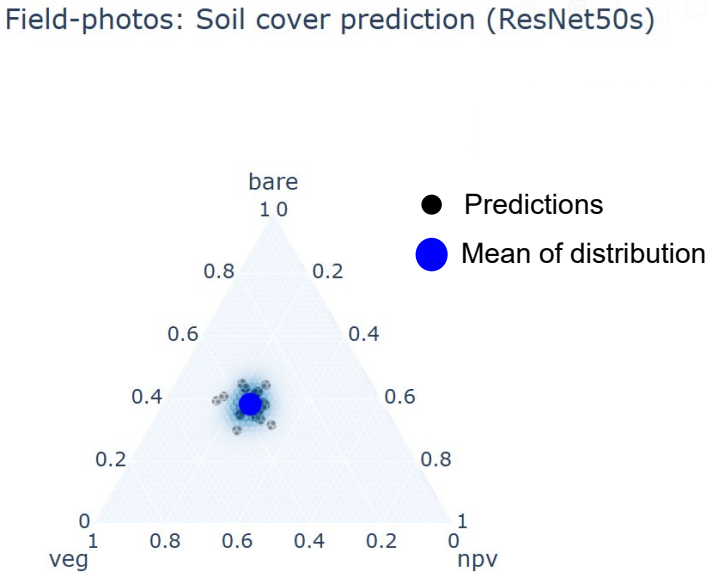
3 fine-tuned ResNet50 (CNN) output a % per class

3 models X 5 photos = 15 predictions per location

bare: 0.36±0.05
npv: 0.26±0.02
veg: 0.38±0.05



Scenarios with one class are the most common

The ensemble model is trained on 3’800 LUCAS 2018 and 2022 locations (13’000 photos)

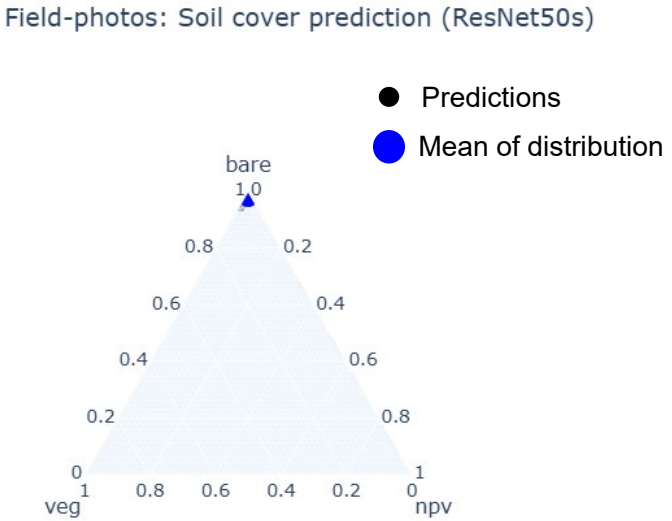
bare: 0.99±0.00
npv: 0.00±0.00
veg: 0.00±0.01

bare: 0.97±0.02
npv: 0.01±0.01
veg: 0.02±0.02

bare: 0.99±0.01
npv: 0.00±0.00
veg: 0.01±0.01

bare: 0.99±0.01
npv: 0.00±0.00
veg: 0.01±0.01

bare: 0.98±0.01
npv: 0.00±0.00
veg: 0.02±0.01



The Dirichlet distribution is concentrated at one corner

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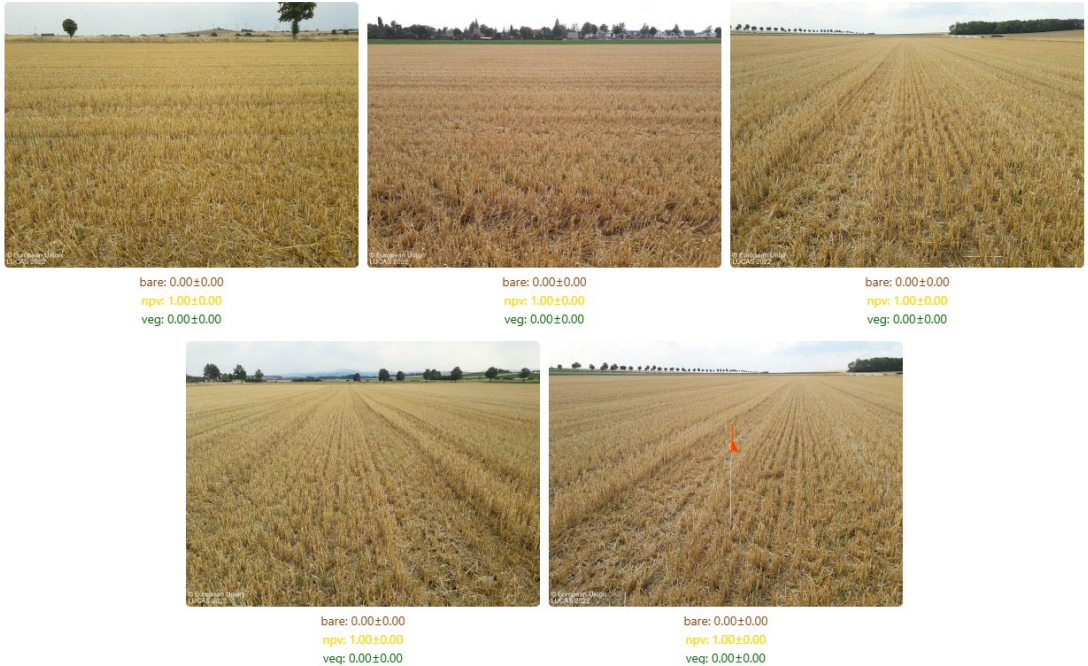

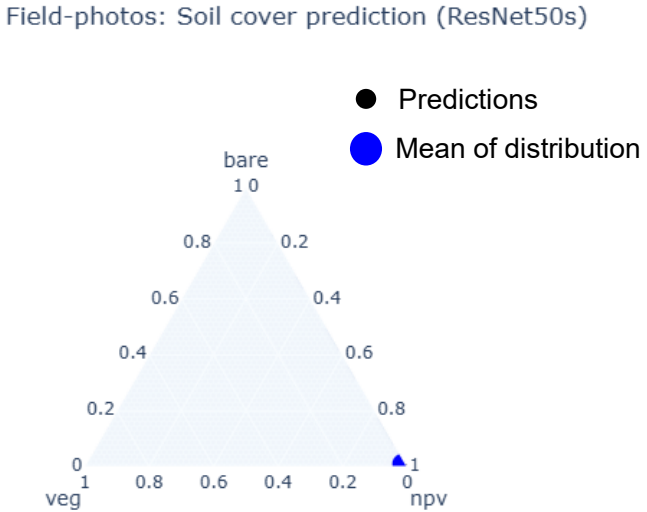

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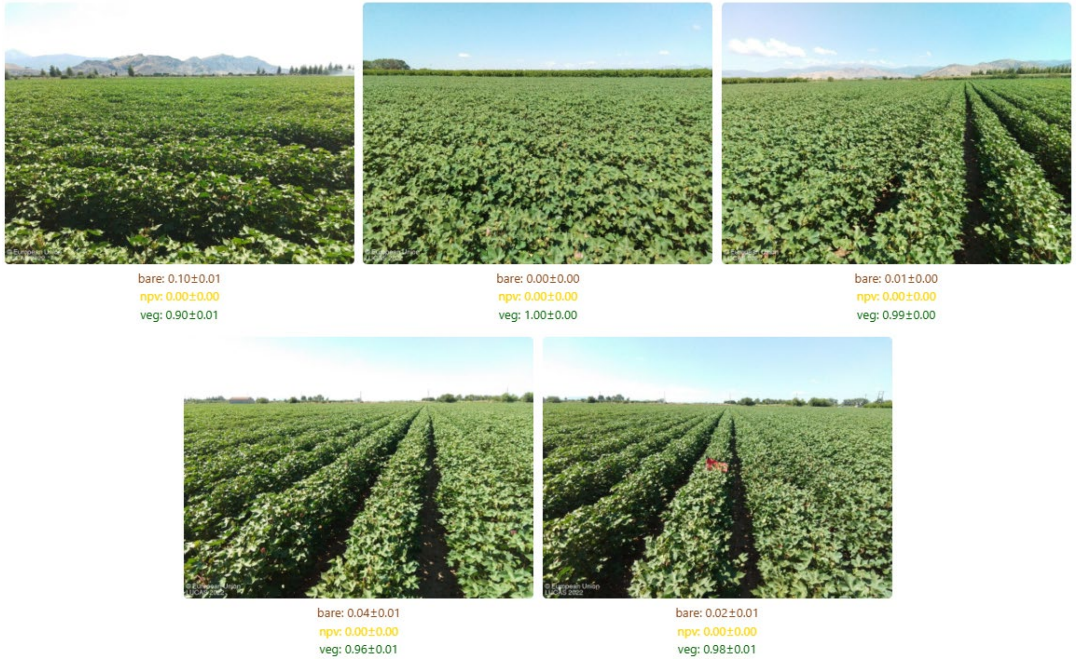

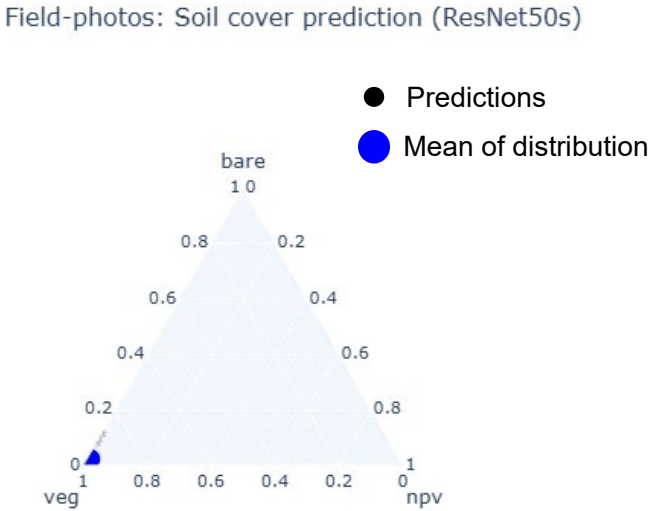

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Noisy locations are identified

The ensemble model is trained on 3’800 LUCAS 2018 and 2022 locations (13’000 photos)

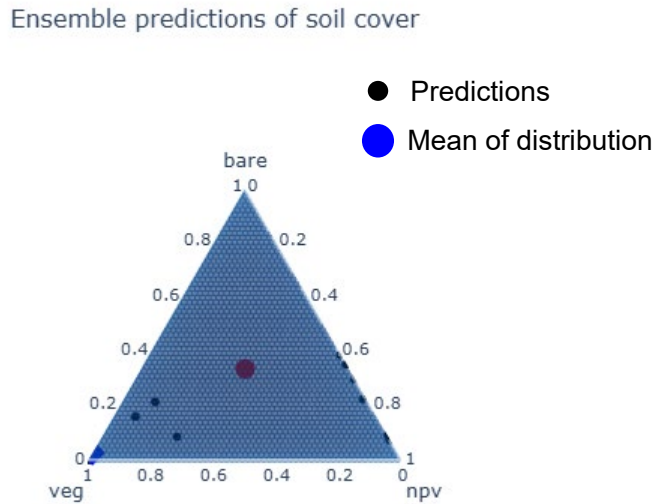

bare: 0.13±0.07
npv: 0.86±0.07
veg: 0.01±0.01


bare: 0.15±0.05
npv: 0.14±0.07
veg: 0.71±0.04


bare: 0.34±0.04
npv: 0.65±0.04
veg: 0.01±0.00


bare: 0.00±0.00
npv: 0.00±0.00
veg: 1.00±0.00

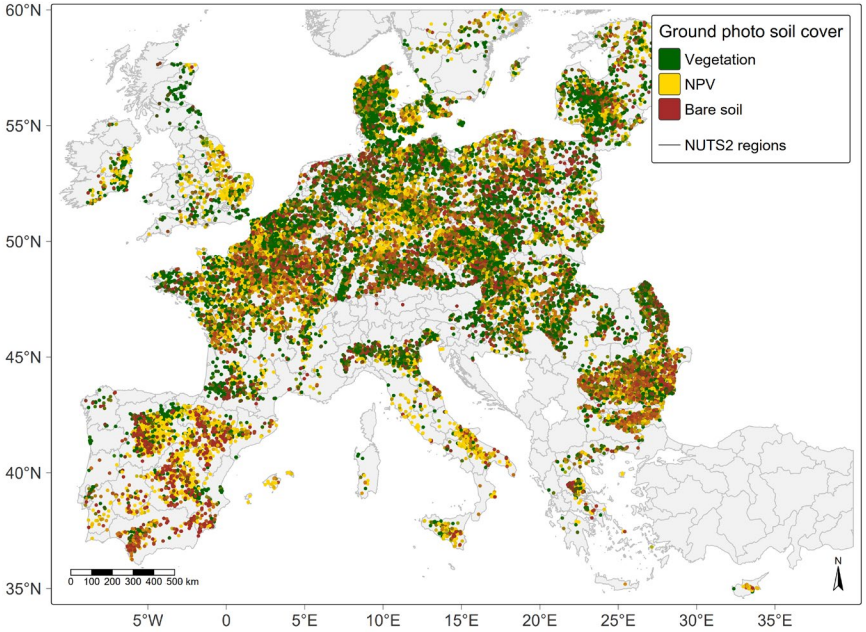

bare: 0.01±0.01
npv: 0.00±0.00
veg: 0.98±0.01



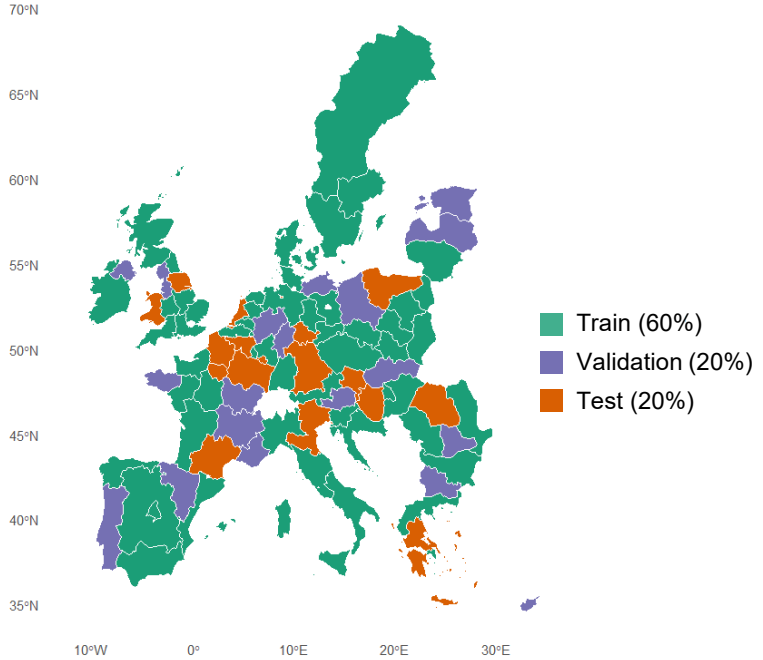
The Dirichlet distribution is spread over the triangle (low concentration)

A reference dataset is automatically generated

The CNN model is applied to photos acquired in 26’000 locations from LUCAS 2018+2022



Predicted soil cover on the date of photo acquisition



Dataset is split regionally to avoid spatial autocorrelation

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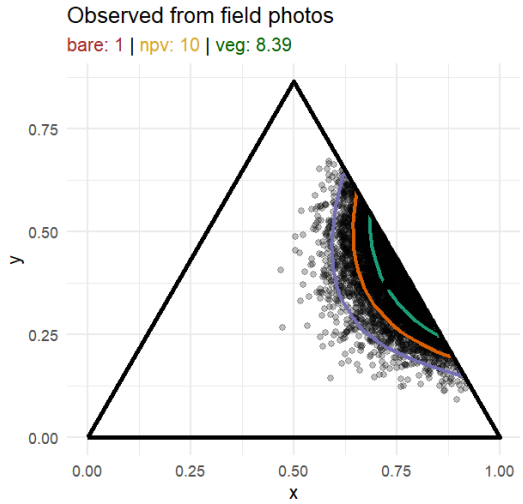
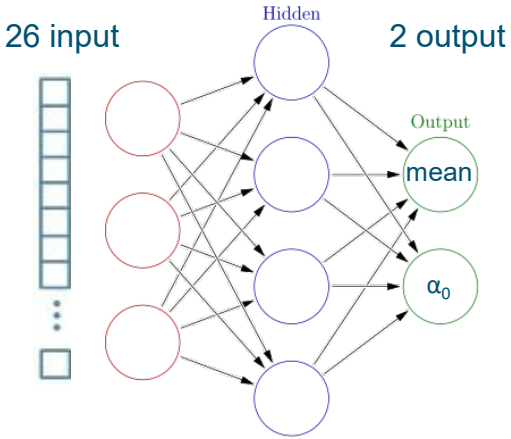
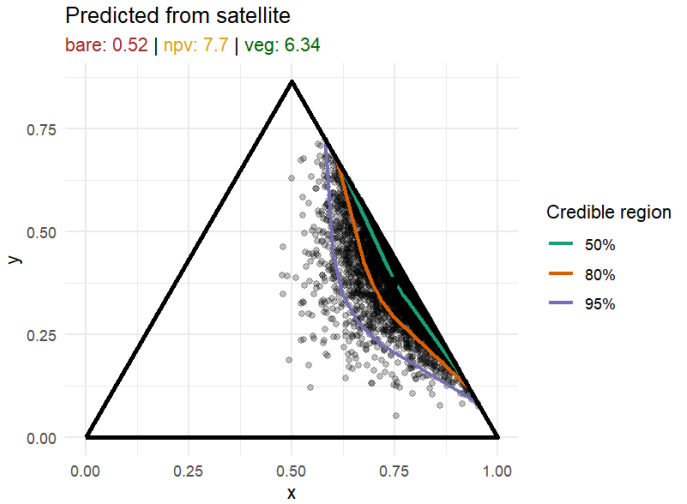
A satellite-based MLP is trained on LUCAS photos

Sentinel-1 and Sentinel-2 bands and indices as input, a Dirichlet distribution as output







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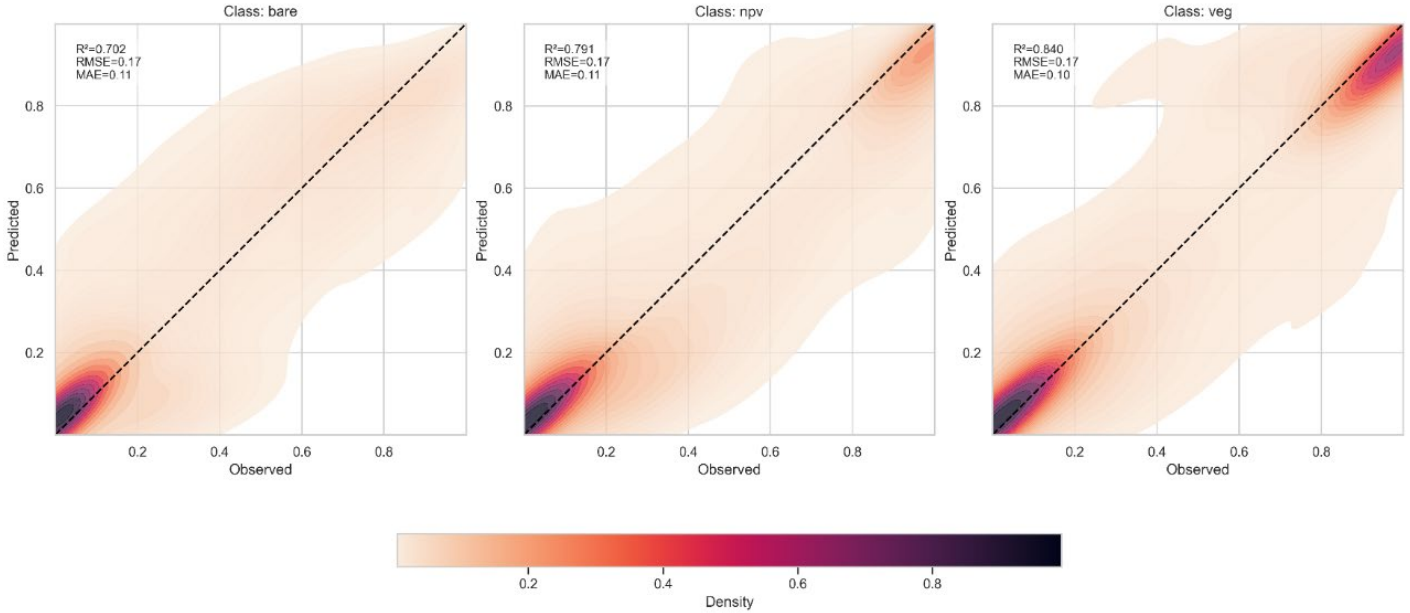
Satellite-based MLP preliminary results

Sentinel-1 and Sentinel-2 bands and indices as input, a Dirichlet distribution as output

Observed (ground-photo) vs predicted (satellite-based): results on test set

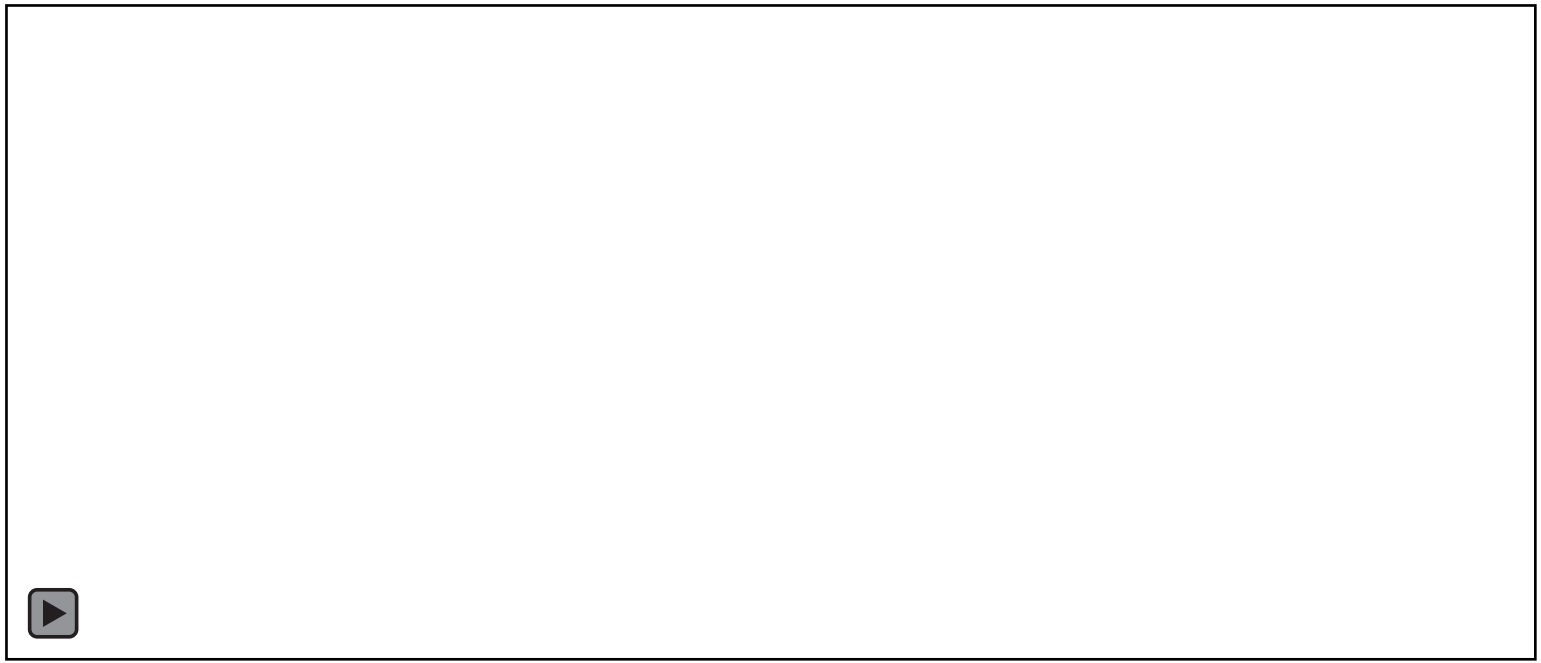


The PhenoCam Network as temporal validation

Example of a field in Denmark where a fixed camera acquires photos daily

PhenoCam daily acquisitions

Satellite-based 10-days predictions



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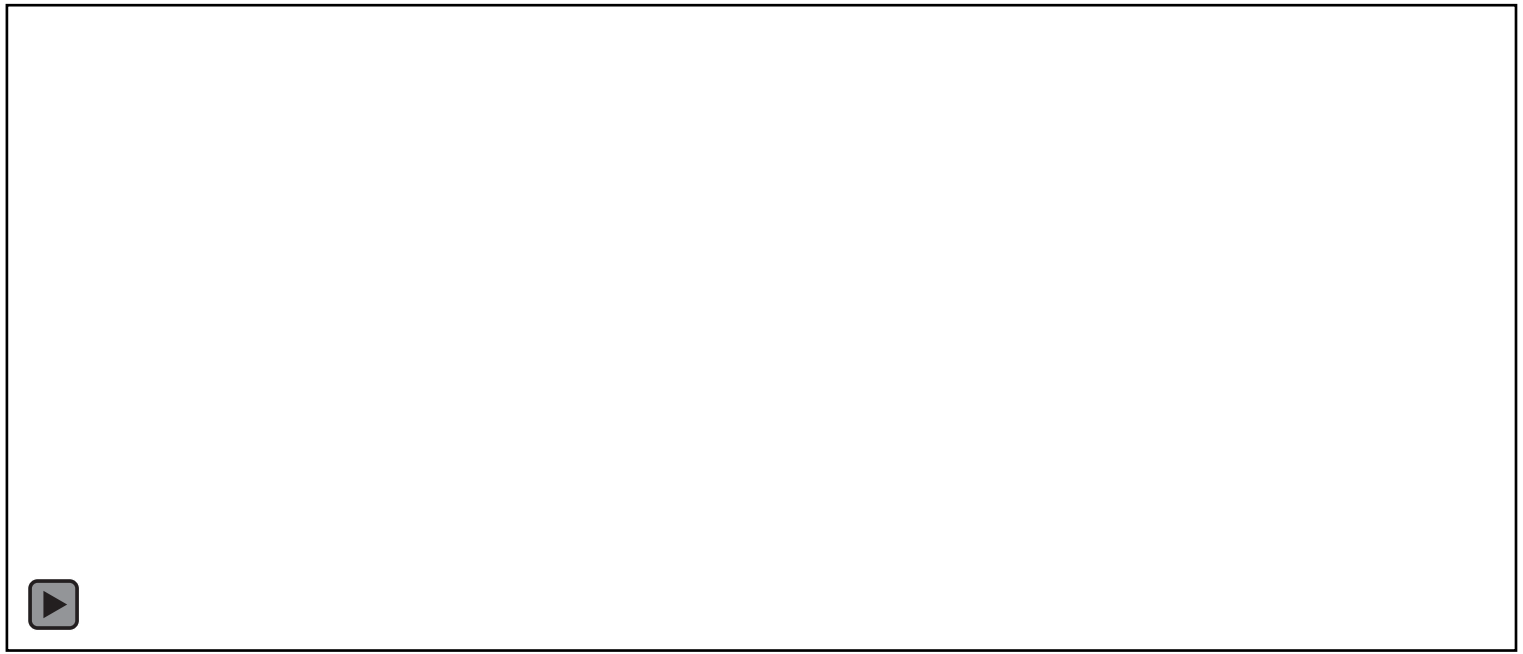
The PhenoCam Network as temporal validation

Example of a field in Italy where a fixed camera acquires photos daily

PhenoCam daily acquisitions

Satellite-based 10-days predictions



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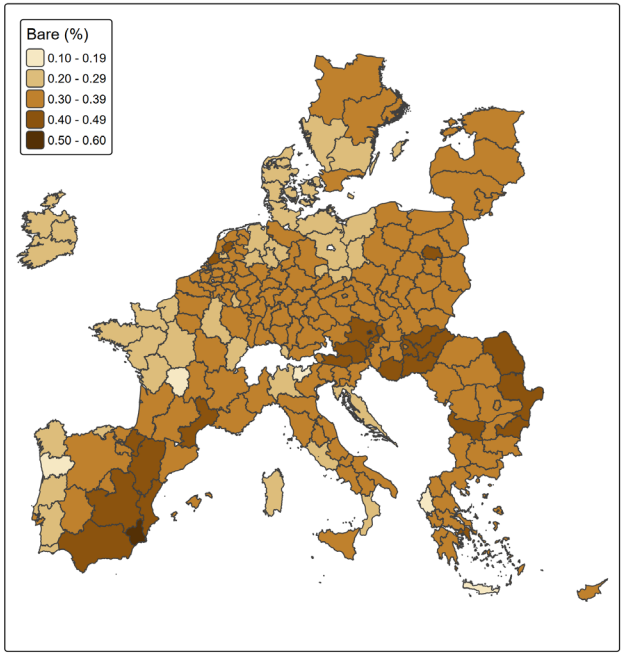
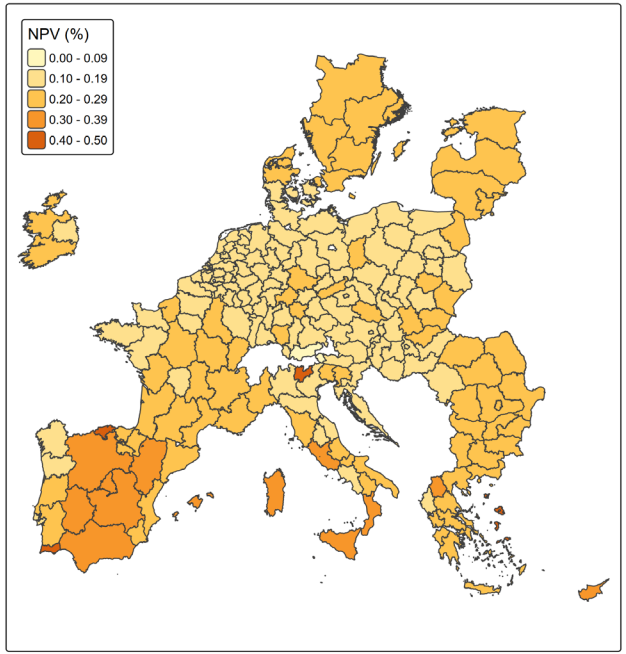
Example of aggregated NUTS2 predictions

Soil cover is inferred from 2020 to 2023 for 15’000 LUCAS 2022 locations

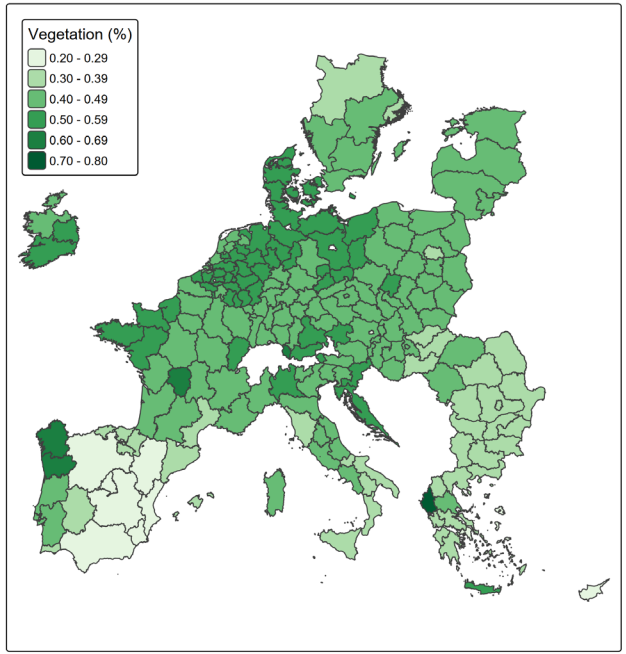
Bare cover - LUCAS points (3-year mean)



NPV cover - LUCAS points (3-year mean)



Vegetation cover - LUCAS points (3-year mean)



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Take away messages

- **Geo-tagged time-stamped ground photos** can be an invaluable source of information for remote sensing models

- Satellite-based models provide options to **monitor the adoption of sustainable farming practices** at the field level, across time and space

- **Policymakers and farmers alike need this information**, as we cannot manage what we cannot measure

Thank you for your attention!

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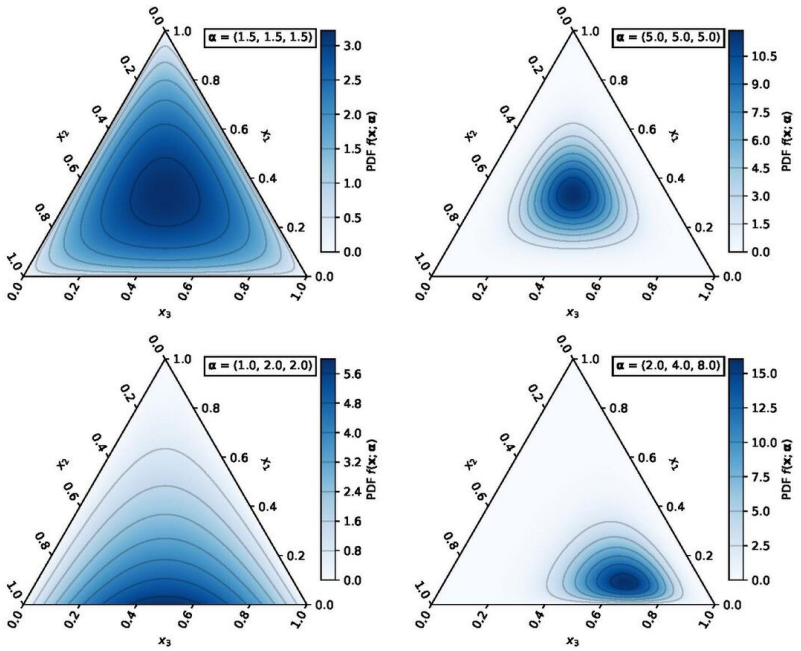
Dirichlet distribution describes ResNet50 predictions

K proportional data are described by k parameters (alphas)



$$\alpha_0 = \sum_{i=1}^{K=3} \alpha_i$$

$$Mean_i = \frac{\alpha_i}{\alpha_0}$$

$$X_i \sim Beta(\alpha_i,\ \alpha_0 - \alpha_i)$$

Alphas are constrained in the range [1,100]